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EVALUATION OF JP-5 TURBINE FUEL IN THE SINGLE-CYLINDER CUE 1790 DIESEL ENGINE

FINAL REPORT
AFLRL No. 119

by

Richard B. Moon
U. S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas

under contract to

U. S. Army Mobility Equipment Research and Development Command
Energy and Water Resources Laboratory
Fort Belvoir, Virginia

Contract No. DAAK70-79-C-0060

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Performance and endurance tests of JP-5 turbine fuel in a single-cylinder assembly (CUE "Cooperative Universal Engine" 1790) from the Teledyne Continental Motors 12-cylinder AVDS 1790-2C (RISE) 4-cycle diesel engine were conducted from 15 August 1979 to 30 August 1979 at AFLRL. The performance test compared fuel consumption and horsepower of the CUE 1790 when operating on JP-5 turbine fuel in place of diesel fuel while the endurance test compared engine wear and deposits when operating the CUE 1790 on JP-5 instead of → over

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diesel fuel.

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The performance test indicated no change in power and a 3+1-percent increase in fuel consumption. The endurance test indicated no change to slightly less wear, less deposits, no change in the oil consumption rate, and nothing unusual or excessive in the used oil analyses. Analysis of the JP-5 indicated a cetane number within diesel fuel specifications.

Although further tests are necessary to define the effect of random variables on the test results, from this test it can be concluded that the use of JP-5 in the CUE 1790 resulted in no appreciable loss in performance or service life. As a result, JP-5 is considered to be a satisfactory alternative fuel for use in the AVDS 1790-2C diesel engine.

FOREWORD

This work was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL) located at Southwest Research Institute, San Antonio, Texas under contract DAAK70-79-C-0060 during the period June 1979 through November 1979. The work was funded by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, Virginia, with Mr. F.W. Schaekel (DRDME-GL) serving as contract monitor. Project technical monitor was Mr. M.E. LePera, MERADCOM-DRDME-GL.

The author acknowledges the contributions of Messrs. F.C. Owens for assistance in test planning, L. Sievers for assistance in conducting the tests, and E. Lyons for assistance in engine ratings.

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TABLE OF CONVERSION FACTORS

Multiply	By	To Obtain Equivalent Number of
pounds per hour (lb/hr)	0.454	kilograms per hour (kg/hr)
degrees Fahrenheit (°F)	(°F-32)/1.8	degrees Celsius (°C)
inches of mercury (in. Hg)	3.39	kiloPascals (kPa)
inches of water (in. H_2O)	0.249	kiloPascals (kPa)
foot-pounds (ft-lb)	1.356	Newton-meters (N-m)
horsepower (hp)	0.746	kilowatts (kW)
gallons per brake horsepower-hour (gal./bhp-hr)	5.076	liters per kilowatt-hour (l/kW-hr)
pounds per brake horsepower-hour (lb/bhp-hr)	634.5	grams per kilowatt-hour (g/kW-hr)

I. INTRODUCTION

In order to reduce logistics requirements and assure increased availability of fuels for Army ground-based equipment, MIL-T-5624L, Grade JP-5 turbine fuel[(1)*] has been identified as an alternate fuel in place of the primary VV-F-800B DF-2 diesel fuel.[(2)]

According to Army Regulation AR 703-1, "Coal and Petroleum Products Supply and Management Activities, 15 September 1978," an alternate fuel is "a fuel that provides performance equal to the primary fuel, but may be a restricted item of supply in tactical areas or has environmental limitations. No degradation of performance or service life occurs as a result of the use of an alternate fuel within the prescribed operational range."

MIL-T-5624L, Grade JP-5 is currently specified as an alternate fuel in AR 703-1 for diesel-powered equipment. The decision to include JP-5 as an alternate for DF-2 occurred as a result of two factors. The U.S. Navy at Port Hueneme had conducted considerable work during the 1960's using JP-5 in large bore and medium-speed diesel engines.[(3)] Secondly, the U.S. Army conducted a survey of major diesel engine manufacturers and fuel system suppliers in 1972 to assess the potential problems arising from substitution of JP-5 for DF-2.[(4)] The cumulative results of these two factors ultimately led to the decision that JP-5 was an acceptable substitute for DF-2. However, no formal program was established to develop long-term endurance testing which would have provided reliability-maintainability-durability (RAM) data. Only a limited amount of performance testing was done.[(5)]

More recently, the U.S. Marine Corps (USMC) were considering adopting JP-5 as an alternate fuel for DF-2 because of logistical supply problems. In several meetings and discussions with USMC and U.S. Navy personnel, this RAM data for using JP-5 in the AVDS-1790 engine which powers the main battle tank (M-48/M-60 Series) was considered to be essential to the USMC. Therefore, prior to adoption of JP-5 as an alternate diesel fuel, the USMC have

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* Superscript numbers in parentheses indicate references cited at the end of the report.

requested that a full-scale AVDS-1790-2C engine durability test using the 400-hour mission profile cycle be conducted with JP-5 fuel.

In conjunction with this test, the U.S. Army decided to conduct a parallel program using the research single-cylinder version of the AVDS-1790 engine. This test, performed in cooperation with the USMC request[6] would provide a means for correlating performance of the single-cylinder CUE version with the full-scale AVDS-1790-2C engine test.

The use of JP-5 in diesel engines has raised the questions of adequate fuel injector lubrication, adequate cetane number, reduced power output, increased fuel consumption, increased engine deposits, and increased engine wear. This test is designed to answer some of these questions.

II. PROCEDURE

A. Performance Test

The engine used in this test was a single-cylinder assembly from the Teledyne Continental Motors AVDS 1790-2C 12-cylinder, 4-cycle, diesel engine. The cylinder assembly was mounted on a universal crankcase and designated the CUE (Cooperative Universal Engine) 1790. A photograph of the CUE 1790 is given in Figure 1. Test conditions such as intake air temperature and pressure, exhaust pressure and cylinder cooling air flow were controlled to duplicate the conditions of the full-size AVDS 1790-2C engine. The test instrumentation was calibrated and, as specified by the contract, the performance data were obtained from 1000 to 2400 rpm at the conditions described in Table A-1 of Appendix A. The test fuel was referee-grade DF-2 diesel fuel (AL-7225-F) MIL-F-46162A(MR) Grade II[7], and the test lubricant conformed to MIL-L-2104C specifications.[8]

B. Endurance Test

The CUE 1790 engine was also used for the 250-hour endurance test. In order to have a base for comparison, the lubricant and test conditions were

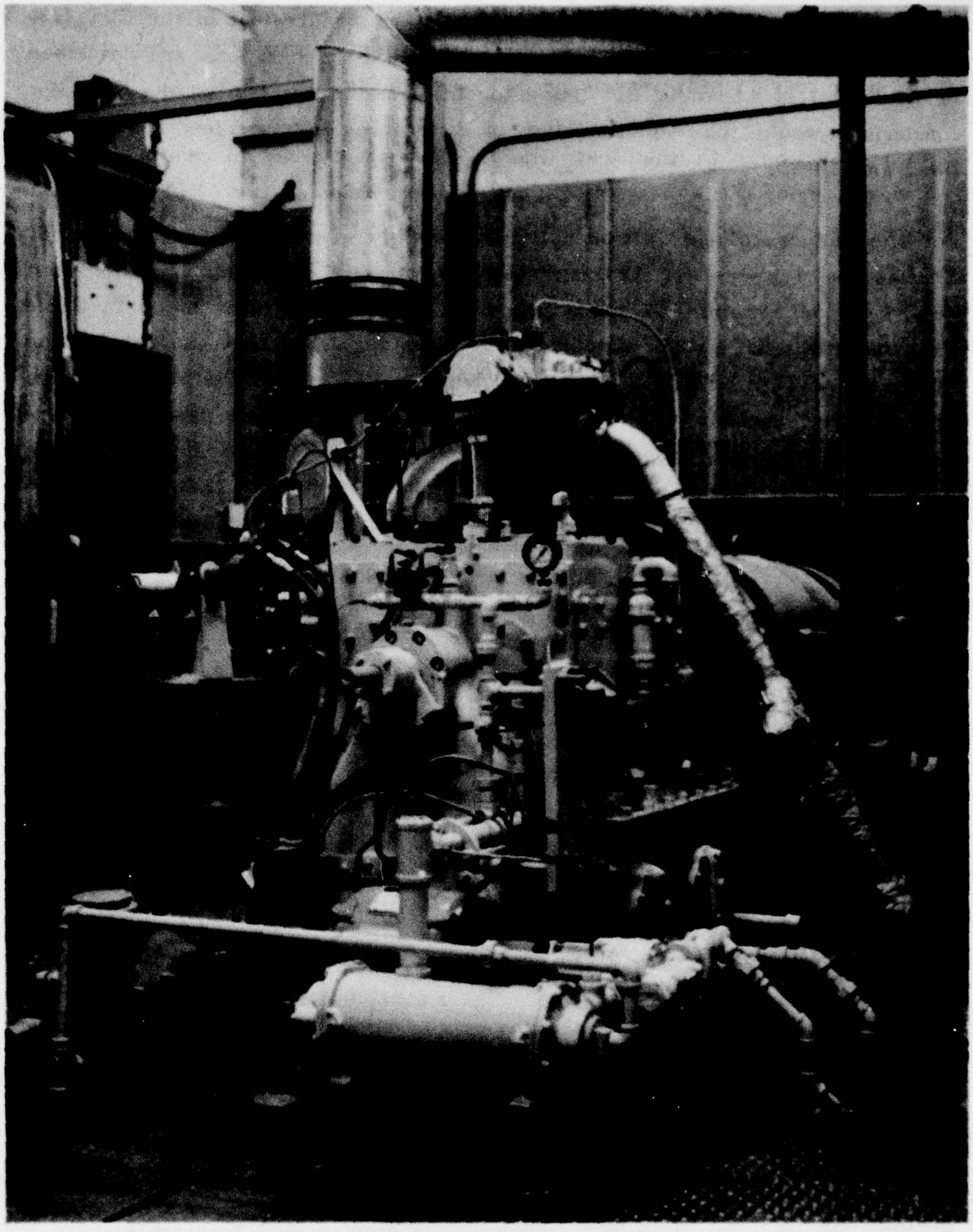

FIGURE 1. AVDS 1790-2C SINGLE-CYLINDER ASSEMBLY MOUNTED ON "COOPERATIVE UNIVERSAL ENGINE" CRANKCASE

made identical to those of a previous 250-hour endurance test in the CUE 1790 using DF-2 (AL-7225-F) as the fuel.[9] These test conditions are described in Table B-1 of Appendix B. Using the DF-2 endurance test as the basis for comparison would allow determination of differences between test results with DF-2 and JP-5.

For the endurance test, a new cylinder assembly was measured and installed. The engine was run for 20 hours per day at test conditions and was shut down for the remaining 4 hours per day. At the test times listed in Table B-11 of Appendix B, oil samples were taken for laboratory analysis of the lubricant, and oil additions were recorded. At the end of the 250-hour test, the cylinder assembly was disassembled, the critical engine dimensions were remeasured, and the components were rated for deposits according to Coordinating Research Council (CRC) methods for diesel engines. The test fuel and test lubricant for the endurance test were identical to the ones used in the performance test.

III. RESULTS AND DISCUSSION

Table 1 summarizes the performance and endurance tests performed during this program. The table compares power, fuel consumption, wear, deposits, engine component condition, and oil consumption when using DF-2 versus using JP-5 fuels. A more detailed discussion is included in the following sections.

TABLE 1. SUMMARY OF THE EFFECTS OF JP-5 VERSUS DF-2 IN THE SINGLE CYLINDER CUE 1790 DIESEL ENGINE

	DF-2	JP-5
Performance (1000-2400 rpm; rated power)		
Average Power, Bhp (kW)	43(32)	43(32)
Average BSVC, gal./Bhp-hr (l/kW-hr)	0.062(0.315)	0.064(0.325)
Endurance (250-hr steady-state test)		
Average Cylinder Liner I.D. Change, in. (mm)	+0.0005(+0.013)	+0.0004(+0.010)
Average Piston Skirt O.D. Change, in. (mm)	-0.0009(-0.023)	-0.0015(-0.038)
Average Piston Ring End Gap Change, in. (mm)	+0.002(+0.05)	0.000(0.000)
Piston WTD* Rating	253	322
Average Oil Consumption Rate, lb/hr (kg/hr)	0.21(0.096)	0.21(0.096)
Engine Deposits and Condition Description of Rings, Pistons, Valves, Cylinder Rod Bearing, and Fuel Injector	Normal	Normal

* Weighted Total Deposit

A. Performance Test

Table A-2 of Appendix A gives the results of the performance test. The differences in power when changing from DF-2 to JP-5, across the engine speed range tested, ranged from a 4-percent loss to a 3-percent increase. The average change in power was 0 percent. The differences in fuel consumption when changing from DF-2 to JP-5 in the CUE 1790 range from no change to a 5-percent increase in fuel consumption, with the average being a 3-percent increase.

Since diesel engine injection systems supply fuel on a volumetric basis, the conventional measure of fuel consumption, brake specific fuel consumption (BSFC), having units of lb/bhp-hr or kg/kW-hr did not correctly show the differences in fuel consumption and vehicle range between fuels that had much different densities. As a result of this, a different measure of fuel consumption was adopted, having the name brake specific volumetric consumption (BSVC) and the units of gal./bhp-hr or l/kW-hr.

Figures A-1 to A-3 (Appendix A) are included to show the general changes in torque, power, and BSVC with rpm. Note that the DF-2 and JP-5 data points on the torque and power curves are quite close to each other in most cases, and that the torque or power points of neither fuel are distinctly above or below the other across the rpm range. This is in agreement with the average change in power of 0 percent mentioned earlier. In the BSVC curve, the JP-5 points are consistently above the DF-2 points, indicating an increase in fuel consumption. This increase agrees with the 3-percent average increase in fuel consumption calculated in Table A-2.

The percentage figures given for changes in power and fuel consumption have a tolerance of approximately ±1 percent. When utilizing these percentage figures, the tolerance should be included for effective interpretation.

B. Endurance Test

Tables B-2 and B-3 of Appendix B summarize the operating conditions for the DF-2 and JP-5 endurance tests, respectively. These summaries are a measure

of the constancy of test conditions achieved for the tests. The mean is the average value for the variable, and the standard deviation is a measure of how closely the variable was controlled around the mean.

Tables B-4 and B-5 of Appendix B present the before and after test measurements of critical engine components for the DF-2 and JP-5 tests, respectively.

Comparison of the two tables shows that cylinder liner wear between the two fuels is identical within the measuring limits. The measurements that show a decrease in inside diameter are not considered to be the result of wear and are not included in the consideration of relative wear. The piston skirt diameter changes are within 0.0006 inch (0.015 mm) of each other and can be taken to be identical. The piston ring end gaps showed an average 0.002 inch (0.05 mm) increase in the DF-2 test and an average 0.000 (0.00 mm) inch change in the JP-5 test. Therefore, ring wear appears to be slightly less with JP-5 as a fuel.

Tables B-6 and B-7 of Appendix B show the CRC deposit ratings of the CUE 1790 rating piston for each test. Being a numerical rating, it is a precise way to indicate the quantity and type of deposits. Examination of the ratings indicates that the DF-2 piston had 100-percent hard carbon in the Nos. 1 and 2 ring grooves, while the JP-5 piston had only 45- and 65-percent hard carbon in the Nos. 1 and 2 ring grooves, respectively. The ring lands of the JP-5 piston also had a lower carbon demerit rating than the DF-2 piston. The lacquer ratings indicate that there was no appreciable lacquer on the DF-2 piston, while there was some light lacquer on the JP-5 piston. A 22-percent lower weighted total piston deposits rating illustrates that the piston in the JP-5 fueled engine had significantly less deposits than the DF-2 fueled engine.

The two tables (Tables B-8 and B-9) that describe the deposits and condition of engine components show that the components of both test engines are virtually identical. The exception is the lower carbon deposit demerit ratings that were given to the JP-5 fueled engine parts, which is in accordance with the previously discussed piston ratings.

Examination of the fuel injector revealed that the JP-5 injector resembled the condition of the DF-2 fueled injector quite closely. The only observable difference was that the JP-5 injector had a small (1 mm x 6 mm) gall on the upper portion of the pintle. The DF-2 injector had very slight galls on the pintle upper portion. Neither pintle had step wear on the tip or enlarged nozzle holes. Both had very clean pintles with varnishing of the tip. In view of the limited data, the similarity of the general condition of both injector nozzles, and other reports[3], the small gall on the JP-5 injector is not considered fuel-related wear.

Table B-10 of Appendix B presents the total oil consumption for both tests and Figure B-1 of Appendix B presents the same data graphically. From the table and graph, it can be seen that the total oil consumption for the tests are quite close to each other, giving identical rates of consumption. The knee in the DF-2 oil consumption graph can be attributed to the nonregular addition of oil during that portion of the test. Table B-11 of Appendix B gives the characteristics of the new oil and the change in oil characteristics with time during the JP-5 test. Figures B-2 through B-5 give the infrared spectra of the oil as the test progresses. Nothing unusual or excessive was noted in the oil analyses. Since the CUE 1790 engine has a large crankcase oil volume relative to the power of the engine, the oil remains relatively unstressed and stable for the test period. If the fuel causes the oil to degrade, leading to excess deposits, then the large sump volume may understate the effects of the fuel on the engine.

As indicated by the operating conditions summary, the power remained constant throughout the test. There was no drop in power as the test progressed to indicate increasing wear in the injection nozzle, rings, valves, or other components.

IV. CONCLUSIONS

Using JP-5 in the CUE 1790 engine resulted in a slight increase in fuel consumption, although power was unaffected. It also resulted in no change to slightly less wear, less deposits, and no change in the oil consumption. Analysis of the JP-5 indicated that with a cetane number of 51, it meets the

minimum VV-F-800B diesel fuel minimum cetane number specification of 45 (see Table 2). From these facts, the conclusion can be drawn that JP-5, using a MIL-L-2104C lubricant, is considered to be a satisfactory alternative fuel in the AVDS 1790-2C diesel engine.

Since this is a single test of the compatibility of JP-5 in the CUE 1790 engine, the effect of random variables on the test results can not be evaluated. Statistical analysis of a number of identical tests would provide a measure of the variance of test results and greatly increase the confidence that can be placed in the test results.

V. RECOMMENDATIONS

To provide greater insight as to potential performance limitations arising from the use of JP-5 in other ground-based equipment, the following actions are recommended:

- Conduct a series of identical engine tests of JP-5 in the CUE 1790 engine, or another single cylinder version of the AVDS 1790 more suited to lubricant testing than the *CUE 1790*, in order to increase the data base and thus the accuracy of the test results.

- Conduct a series of identical full-scale engine tests of JP-5 in the AVDS 1790-2C engine. Testing in the full-scale engine would yield results more representative of field testing than the CUE 1790 engine tests, although far more costly, and the series of tests would increase the accuracy of the test results.

- Conduct series of identical full-scale engine tests of JP-5 in the other engines of the Army inventory. The information gained by testing JP-5 in one type of engine cannot necessarily be extended to other types of engines.

TABLE 2. COMPARISON OF TEST FUEL PROPERTIES AND SPECIFICATIONS FOR JP-5 AND REFEREE DIESEL FUELS

	ASTM Test Method	Base Fuel AL-7225-F DF-2*	Test Fuel AL-8570-T JP-5	Specification MIL-F-46162A Referee Diesel Fuel Grade II	Specification VV-F-800B** DF-2 CONUS	Specification MIL-T-5624L+ JP-5
Distillation, °F(°C)	D 86					
Initial Boiling Point		331(166)	344(173)	340(171) to 400(204)	NR	NR
10% Recovered		424(218)	384(196)	400(204) to 460(238)	NR	401(205) max
50% Recovered		471(244)	417(214)	470(243) to 540(282)	Report	NR
90% Recovered		556(291)	456(236)	550(288) to 610(321)	640(338) max	NR
End Point		676(358)	483(251)	580(304) to 660(349)	700(371) max	554(290) max
Residue, vol%		1.5	1.4	NR++	NR	1.5 max
Loss, vol%		0.0	1.4	NR	NR	1.5 max
Flash Point, °F(°C)	D 93	142(61)	131(55)	133(56) min	126(52) min	140(60) min
Cloud Point, °F(°C)	D 2500	-6(-21)	-56(-49)	9(-13) max	***	NR
Pour Point, °F(°C)	D 97	-11(-24)	-53(-47)	0(-18) max	Report	NR
Viscosity at 100°F (37.8°C), cSt	D 445	2.05	1.54	2.2 to 3.2	2.0 to 4.3	NR
Neut. No., mgKOH/g	D 664	0.01	0.01	0.01 max	NR	0.015
Existent Gum, mg/100ml	D 381	1.9	0.4	1.0 max	NR	7.0 max
Water and Sediment, vol%	D 1796	0.01	0.00	0.01 max	0.01 max	NR
Cetane Number	D 613	48	51	42 min	45 min	NR
Density, lb/gal (gm/ml) at 60°F(15.6°C)	D 287	7.0(0.844)	6.8(0.814)	7.0(0.840) to 7.2(0.860)	Report	6.6(0.788) to 7.1(0.845)
Net Heat of Combustion, Btu/gal (MJ/l)	D 240	128300(36.0)	124000(34.8)	Report	NR	120800(33.6) min
Sulfur, wt%	XRF	0.35	0.07	0.35 to 0.70	0.50 max	0.40 max
Carbon Residue on 10% bottoms, wt%	D 524	0.15	0.07	0.20 max	0.35 max	NR
Ash, wt%	D 482	0.001	0.000	0.02 max	0.01 max	NR
Copper Strip Corrosion 2 hr at 122°F(50°C)	D 130	1A	1A	Report	3 max	1B max
Hydrogen, wt%	+++	13.2	14.3	NR	NR	13.5 min

* MIL-F-46162 Referee, Fuel, Diesel
** Dated 2 April 1975
\+ Dated 18 May 1979
++ NR = Not Required
*** See Appendix I of VV-F-800B for limiting temperature value
+++ Microcombustion

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APPENDIX A

PERFORMANCE TEST DATA

TABLE A-1. CUE 1790 PERFORMANCE TEST CONDITIONS

Speed, rpm	1000	1300	1600	1800	1900	2200	2400
Fuel Consumption, lb/hr	10.0	13.5	17.0	18.8	20.6	24.1	26.5
(kg/hr)	(4.54)	(6.12)	(7.71)	(8.53)	(9.34)	10.93)	(12.02)
Intake Air Temp, °F	100	134	168	188	202	236	260
°C	(38)	(51)	(76)	(87)	(94)	(113)	(127)
Intake Air Pressure, in. Hg	32.0	37.5	43.5	47.0	50.0	57.0	62.0
(kPa)	(108)	(127)	(147)	(159)	(169)	(193)	(210)
Exhaust Gas Pressure, in. Hg	29.5	33.5	37.5	39	42	46.5	49.5
(kPa)	(100)	(113)	(127)	(132)	(142)	(157)	(168)
Cooling Air ΔP, in. H_2O	2	4	5	6.5	7	9	11
(kPa)	(0.5)	(1.0)	(1.3)	(1.6)	(1.7)	(2.2)	(2.7)
Oil Temperature, °F	170	170	170	170	170	170	170
°C	(77)	(77)	(77)	(77)	(77)	(77)	(77)
Injection timing, °BTDC at Inj.	18	19	21	22.5	23.5	23.5	23
at Pump	24.5	27	30	32.5	34	35.5	35.5

TABLE A-2. JP-5 AND DF-2 IN THE CUE 1790 FULL RACK PERFORMANCE TEST DATA

Engine Speed, rpm	Torque, ft-lb(N-m)		% Change	Power, Bhp(kW)		% Change	BSVC Gal/Bhp-Hr (1/kW-hr)		Change
	DF-2	JP-5		DF-2	JP-5		DF-2	JP-5	
1000	112(152)	112(156)	0	21(16)	21(16)	0	0.067(0.340)	0.069(0.350)	+3
1300	115(156)	115(156)	0	29(22)	29(22)	0	0.067(0.340)	0.069(0.350)	+3
1600	131(178)	132(179)	+1	40(30)	40(30)	+1*	0.060(0.305)	0.061(0.310)	+2
1800	137(186)	137(186)	0	47(35)	47(35)	0	0.057(0.289)	0.058(0.294)	+1
1900	143(194)	142(193)	-1	52(39)	52(39)	-1*	0.057(0.289)	0.059(0.299)	+5
2200	132(179)	132(179)	0	55(41)	55(41)	0	0.062(0.315)	0.064(0.325)	+2
2400	120(163)	120(163)	0	55(41)	55(41)	0	0.069(0.350)	0.070(0.355)	+2
2400	120(163)	120(163)	0	55(41)	55(41)	0	0.069(0.350)	0.070(0.355)	+2
2200	136(184)	135(183)	-1	57(43)	57(43)	-1*	0.061(0.310)	0.062(0.315)	+2
1900	141(191)	136(184)	-4	51(38)	49(37)	-4	0.056(0.284)	0.061(0.310)	+9
1800	140(190)	140(190)	0	48(36)	48(36)	0	0.055(0.279)	0.056(0.284)	+3
1600	132(179)	136(184)	+3	40(30)	42(31)	+3	0.061(0.310)	0.061(0.310)	0
1000	115(156)	112(152)	-3	22(16)	21(16)	-3	0.065(0.330)	0.069(0.350)	+5
1300	116(157)	116(157)	0	29(22)	29(22)	0	0.068(0.345)	0.069(0.350)	+1
Average % Change			0			0			+3

* Although the power figures appear identical, they differed enough in the third significant figure to show a one percent change.

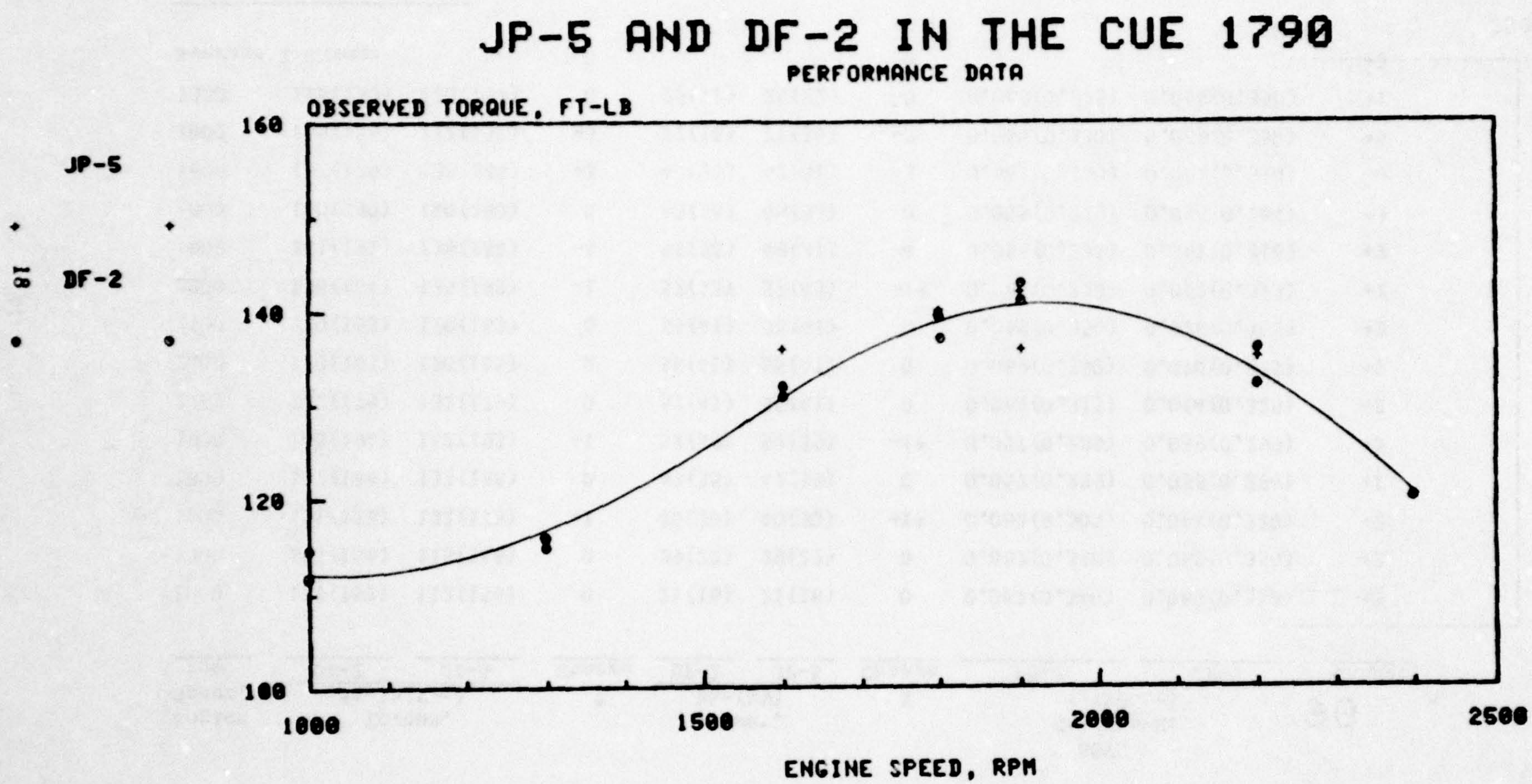


TABLE A-1. OBSERVED TORQUE VERSUS ENGINE SPEED

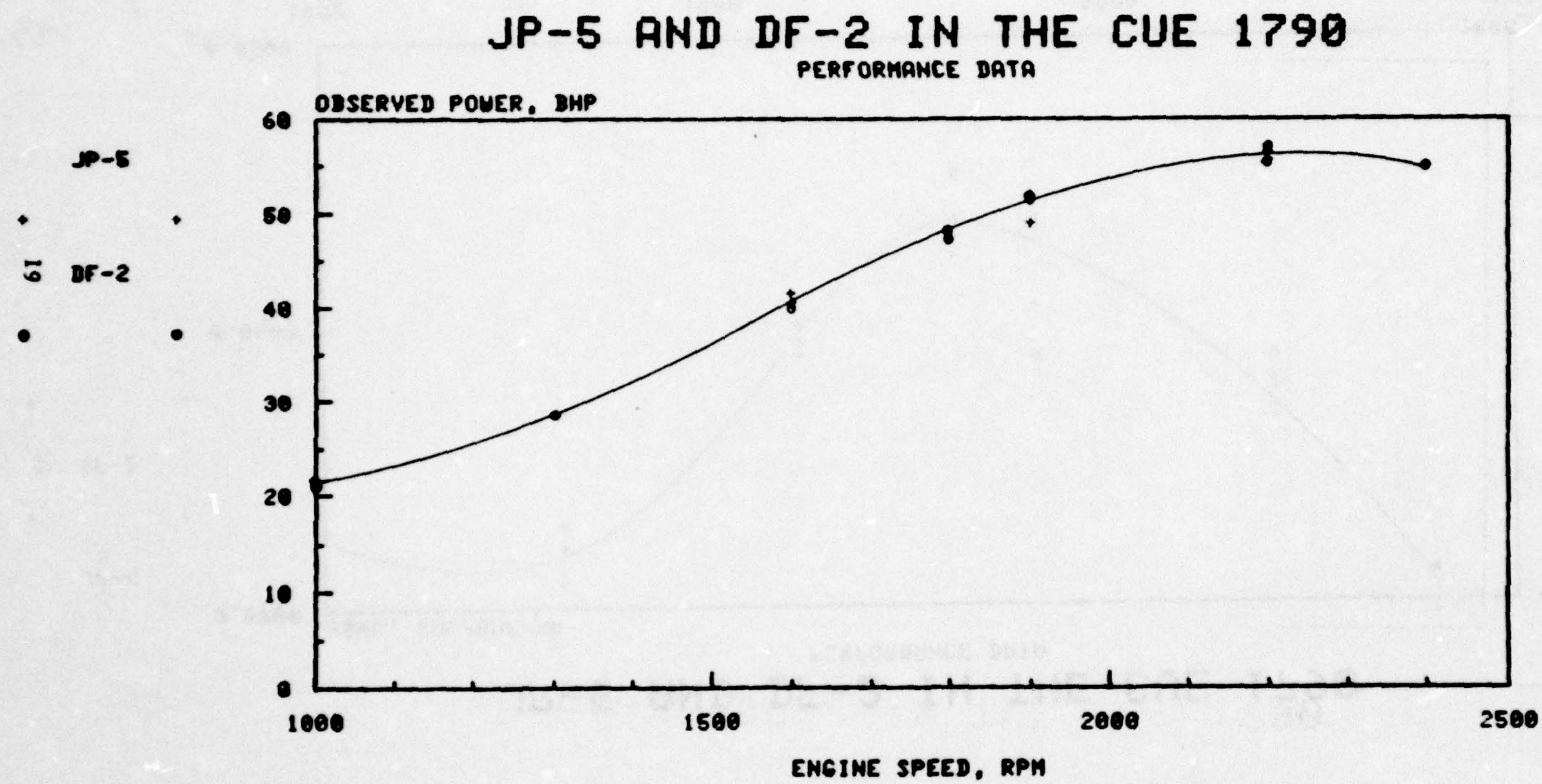


FIGURE A-2. OBSERVED POWER VERSUS ENGINE SPEED

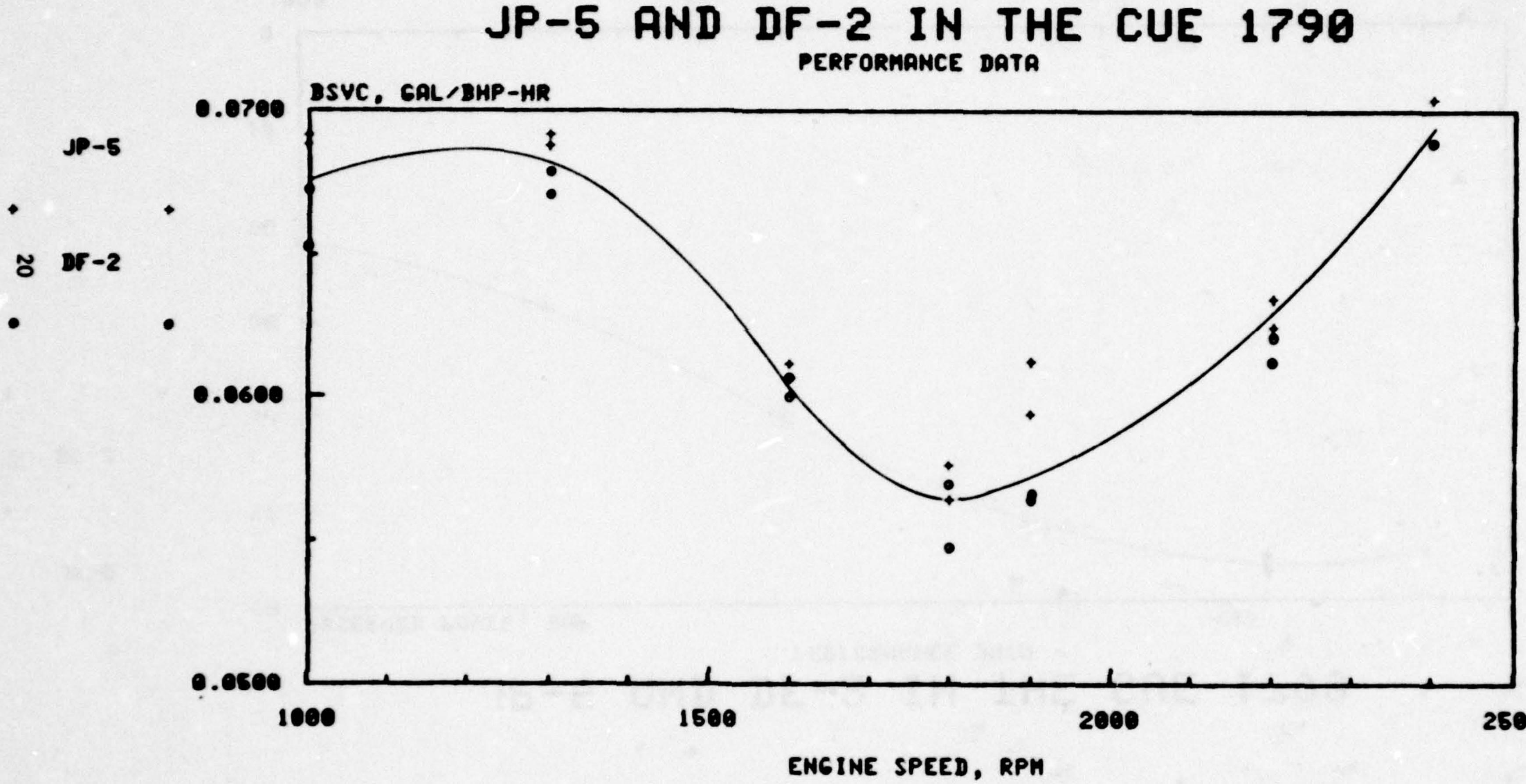


FIGURE A-3. BSVC VERSUS ENGINE SPEED

APPENDIX B

250-HOUR ENDURANCE TEST DATA

TABLE B-1. CUE 1790 ENDURANCE TEST CONDITIONS

Speed, rpm	1800
Fuel Consumption, lb/hr(kg/hr)	18.8(8.54)
Intake Air Temp, °F(°C)	188(87)
Intake Air Pressure, in. Hg(kPa)	47(159)
Exhaust Gas Pressure, in. Hg(kPa)	39(132)
Cooling Air ΔP, in. H_2O(kPa)	6-7(1.5-1.7)
Oil Temperature, °F(°C)	170(77)
Injection timing, °BTDC at Pump	28

TABLE B-2. DF-2 FUEL IN THE CUE 1790 ENGINE

Endurance Test

Operating Conditions Summary

Test Start: 5 May 1978

Test Finish: 16 June 1978

	Mean	Standard* Deviation
Engine Speed, rpm	1805	4
Torque, ft-lb(N-m)	130(176)	2(3)
Fuel Consumption, lb/hr(kg/hr)	18.7(8.49)	0.2(0.009)
Observed Power, Bhp(kW)	45(34)	0.7(0.5)
BSFC, lb/Bhp-hr(g/kW-hr)	0.416(264)	0.009(6)
Temperatures, °F(°C)		
Exhaust Gas	1010(543)	10(6)
Intake Air	188(87)	1(1)
Oil to Engine	170(77)	5(3)
Oil Before Cooler	195(91)	6(3)
Cooling Air In	117(47)	6(3)
Pressures		
Intake Air, in. Hg(kPa)	47.0(159)	0.5(2)
Exhaust Gas, in. Hg(kPa)	38.8(132)	0.4(1)
Cooling Air ΔP, in. H_2O(kPa)	6.3(1.6)	0.3(0.08)
Ambient Conditions		
Wet Bulb Temperature, °F(°C)	75(24)	3(2)
Dry Bulb Temperature, °F(°C)	83(28)	5(3)
Barometric Pressure, in. Hg(kPa)	29.12(98.72)	0.08(0.27)

* 68% of the values for a given variable occur within ±1 standard deviation of the mean; 95% occur within ±2 standard deviations.

TABLE B-3. JP-5 FUEL IN THE CUE 1790 ENGINE

Endurance Test
Operating Conditions Summary
Test Start: 15 August 1979
Test Finish: 30 August 1979

	Mean	Standard* Deviation
Engine Speed, rpm	1803	4
Torque, ft-lb(N-m)	139(188)	1(1)
Fuel Consumption, lb/hr(kg/hr)	18.7(8.49)	0.2(0.09)
Observed Power, Bhp(kW)	48(36)	0.4(0.3)
BSFC, lb/Bhp-hr(g/kW-hr)	0.390(247)	0.005(3)
Temperatures, °F(°C)		
Exhaust Gas	965(518)	20(11)
Intake Air	188(87)	3(2)
Oil to Engine	170(77)	3(2)
Oil Before Cooler	188(87)	5(3)
Cooling Air In	120(49)	9(5)
Pressures		
Intake Air, in. Hg(kPa)	47.2(160)	0.3(1.0)
Exhaust Gas, in. Hg(kPa)	39.1(133)	0.4(1.4)
Cooling Air ΔP, in. H_2O(kPa)	6.3(1.6)	0.3(0.08)
Ambient Conditions		
Wet Bulb Temperature, °F(°C)	76(24)	3(2)
Dry Bulb Temperature, °F(°C)	83(28)	6(3)
Barometric Pressure, in. Hg(kPa)	29.06(98.5)	0.21(0.71)

* 68% of the values for a given variable occur within ±1 standard deviation of the mean; 95% occur within ±2 standard deviations.

TABLE B-4. ENDURANCE TEST
ENGINE DIMENSIONS
DF-2 IN THE CUE 1790 ENGINE
OIL: MIL-L-2104C (AL-6856-L)
TEST TIME: 250 Hours

Cylinder Liner I.D., Inches(Millimeters)

Longitudinal

	Inches(Millimeters)from Bottom of Liner				
	2.25(57)	6.25(159)	8.25(210)	9.75(248)	10.50(267)
Before	5.7527(146.119)	5.7516(146.091)	5.7512(146.080)	5.7504(146.060)	5.7491(146.027)
After	5.7530(146.126)	5.7524(146.111)	5.7518(146.096)	5.7508(146.070)	5.7488(146.020)
Change	0.0003(0.007)	0.0008(0.020)	0.0006(0.016)	0.0004(0.010)	-0.0003(-0.007)

Transverse

	Inches(Millimeters)from Bottom of Liner				
	2.25(57)	6.25(159)	8.25(210)	9.75(248)	10.50(267)
Before	5.7521(146.103)	5.7515(146.088)	5.7510(146.075)	5.7502(146.055)	5.7490(146.025)
After	5.7525(146.114)	5.7520(146.101)	5.7513(146.083)	5.7495(146.037)	5.7486(146.014)
Change	0.0004(0.011)	0.0005(0.013)	0.0003(0.008)	-0.0007(-0.018)	-0.0004(-0.011)

Average Cylinder Liner I.D. Change (excluding negative changes),
Inches(Millimeters): 0.0005(0.013)

Piston Skirt O.D., Inches(Millimeters)

	0.50 Inch(12.7 mm) from Bottom	1.0 Inch(25.4 mm) from Top
Before	5.7415(145.834)	5.7382(145.750)
After	5.7400(145.796)	5.7380(145.745)
Change	-0.0015(-0.038)	-0.0002(-0.005)

Average Piston Skirt O.D. Change, Inches(Millimeters): -0.0009(-0.023)

Piston Ring End Gap, Inches(Millimeters)

	Top	No. 2 Compression	No. 3 Compression	Oil
Before	0.047(1.19)	0.032(0.81)	0.029(0.74)	0.030(0.76)
After	0.048(1.22)	0.034(0.86)	0.031(0.79)	0.031(0.79)
Change	0.001(0.03)	0.002(0.05)	0.002(0.05)	0.001(0.03)

Average Piston Ring Gap change, Inches(Millimeters): 0.002(0.05)

TABLE B-5. ENDURANCE TEST
ENGINE DIMENSIONS
JP-5 IN THE CUE 1790
OIL: MIL-L-2104C (AL-6856-L)
TEST TIME: 250 Hours

Cylinder Liner I.D., Inches(Millimeters)

Longitudinal

	Inches(Millimeters) from Bottom of Liner				
	2.25(57)	6.25(159)	8.25(210)	9.75(248)	10.50(267)
Before	5.7513(146.083)	5.7524(146.111)	5.7530(146.126)	5.7528(146.121)	5.7532(146.131)
After	5.7520(146.101)	5.7524(146.111)	5.7532(146.131)	5.7532(146.131)	5.7535(146.139)
Change	0.0007(0.018)	0.0000(0.000)	0.0002(0.005)	0.0004(0.010)	0.0003(0.008)

Transverse

	Inches(Millimeters) from Bottom of Liner				
	2.25(57)	6.25(159)	8.25(210)	9.75(248)	10.50(267)
Before	5.7514(146.086)	5.7518(146.096)	5.7523(146.108)	5.7527(146.119)	5.7530(146.126)
After	5.7520(146.101)	5.7524(146.111)	5.7528(146.121)	5.7530(146.126)	5.7525(146.114)
Change	0.0006(0.015)	0.0006(0.015)	0.0005(0.013)	0.0003(0.007)	-0.0005(-0.012)

Average Cylinder Liner I.D. Change (excluding negative changes),
Inches(Millimeters): 0.0004(0.010)

Piston Skirt O.D., Inches(Millimeters)

	0.50 Inch(12.7 mm) from Bottom	1.0 Inch(25.4 mm) from Top
Before	5.7415(145.834)	5.7240(146.390)
After	5.7400(145.796)	5.7355(145.682)
Change	-0.0015(-0.038)	+0.0115(+0.292)

Average Piston Skirt O.D. Change (excluding positive changes),
Inches(Millimeters): -0.0015(-0.038)

Piston Ring End Gap, Inches(Millimeters)

	Top	No. 2 Compression	No. 3 Compression	Oil
Before	0.045(1.14)	0.029(0.74)	0.029(0.74)	0.028(0.71)
After	0.045(1.14)	0.030(0.76)	0.029(0.74)	0.028(0.71)
Change	0.000(0.00)	0.001(0.02)	0.000(0.00)	0.000(0.00)

Average Piston Ring Gap Change, Inches(Millimeters): 0.000(0.00)

TABLE B-6

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ____________

TEST HOURS 250

TEST LABORATORY AFLRL

LUBRICANT AL-6856-L

RATER E.R. Lyons DATE 9-10-79

LABORATORY TEST NUMBER JP-5 No. 1

STAND NO. 3 ENGINE NO. CUE 1790

FUEL AL-8570-F

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	252.88

	DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	45	45.00	65	65.00					10	10.00	50	50.00						
CARBON	MHC	0.75	30	22.50																
CARBON	MC	0.50	25	12.50	35	17.50					15	7.50								
CARBON	LC	0.25									5	1.25	30	7.50						
CARBON	VLC	0.15									10	13.125								
CARBON	CARBON RATING		80.00		82.00						31.875		57.50							
LACQUER	BL	0.100																		
LACQUER	DBrL	0.075																		
LACQUER	AL	0.050																		
LACQUER	LAL	0.025											20	.50						
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001					100	0.10	100	0.10					100	0.10	100	0.10	100	0.10
LACQUER	LACQUER RATING						0.10		0.10				0.50		0.10		0.10		0.10	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			80.00		82.50		0.10		0.10		31.875		58.00		0.10		0.10		0.10	

*WEIGHTED TOTAL DEPOSITS

TABLE B-7

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ____
TEST HOURS 250
TEST LABORATORY AFLRL
LUBRICANT AL-6856-L

RATER E.R. Lyons DATE 6-20-78
LABORATORY TEST NUMBER DF-2 No. 1
STAND NO. 3 ENGINE NO. 1790
FUEL AL-7225-F

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	322.51

	DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA %	DEMERIT	AREA %	DEMERIT	AREA %	DEMERIT	AREA %	DEMERIT	AREA %	DEMERIT	AREA %	DEMERIT	AREA %	DEMERIT	AREA %	DEMERIT	AREA %	DEMERIT
CARBON	HC	1.00	100	100	100	100					20	20.00	80	80.00						
CARBON	MHC	0.75																		
CARBON	MC	0.50																		
CARBON	LC	0.25									80	20.00	10	2.50						
CARBON	VLC	0.15																		
	CARBON RATING		100.00		100.00						40.00		82.50							
LACQUER	BL	0.100																		
LACQUER	DBrL	0.075																		
LACQUER	AL	0.050																		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001											10	0.10						
	LACQUER RATING												0.10							
	CLEAN	0					100	0	100	0					100	0	100	0	100	0
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		100		100		0		0		40.00		82.51		0		0		0	

*WEIGHTED TOTAL DEPOSITS

TABLE B-8. ENGINE COMPONENTS
DEPOSITS AND CONDITION DESCRIPTIONS
ENGINE: CUE 1790
TEST FUEL: DF-2 (AL-7225-F)
TEST OIL: MIL-L-2104C (AL-6856-L)
DATE COMPLETED: 15 June 1978

RINGS: All rings are free in their grooves.
No ring face burning.
Normal wear pattern.
All oil control ring slots open.
No. 2 compression ring ID has some heavy carbon.

PISTON: Light scratches (see piston rating sheet).

VALVES: There is some carbon on the intake value face and corresponding pits in the valve seat.
Intake valve tulip deposit rating: 1.0
Exhaust valve tulip deposit rating: 0.25

CYLINDER: Light lacquer on liner.
Normal light scratches.

CONNECTING ROD BEARING: Normal light wear on the top half.

FUEL INJECTOR: Light, normal wear on pintle. No step wear on pintle tip. Nozzle holes not enlarged. Pintle clean and has some very light galling on the upper portion.

TABLE B-9. ENGINE COMPONENTS
DEPOSITS AND CONDITION DESCRIPTIONS
ENGINE: CUE 1790
TEST FUEL: JP-5 (AL-8570-F)
TEST OIL: MIL-L-2104C (AL-6856-L)
DATE COMPLETED: 30 August 1979

RINGS: All rings are free in their grooves
No ring face burning.
Normal wear pattern.
All oil control ring slots open.
No. 2 compression ring ID has some heavy carbon.

PISTON: Light scratches (see piston rating sheet).

VALVES: The intake valve has some pitting on the valve face and has a No. 5 lacquer deposit rating.
Intake valve tulip deposit rating: 0.5
Exhaust valve face is normal and has a No. 9 lacquer deposit rating.
Exhaust valve tulip deposit rating: 0.25

CYLINDER: Light carbon in combustion chamber.
Light lacquer on liner.
Very light wear.

CONNECTING ROD BEARING: Normal light wear on the top half.

FUEL INJECTOR: Light, normal wear on pintle. A slight galling (1mm x 6 mm) was noted on the upper portion of the pintle. The pintle tip had no step wear and the nozzle holes were not enlarged from their original dimension. Pintle very clean, no varnish or deposits on body. Pintle tip has some varnish.

TABLE B-10. DF-2 AND JP-5
ENDURANCE TESTS
OIL CONSUMPTION

DF-2		JP-5	
Test Time, hr	Total Consumption, lb(kg)	Test Time, hr	Total Consumption, lb(kg)
0	0(0)	0	0(0)
9	0(0)	20	7.14(3.24)
15	7.58(3.44)	56	9.22(4.19)
26	7.58(3.44)	84	15.49(7.03)
39	7.58(3.44)	98	17.61(7.99)
55	14.17(6.43)	126	24.21(10.99)
69	27.77(12.61)	168	30.03(13.63)
84	28.27(12.83)	200	36.41(16.53)
99	28.27(12.83)	210	39.39(17.88)
114	28.27(12.83)	224	43.09(19.56)
129	28.39(12.89)	238	50.11(22.75)
144	30.29(13.75)		
159	32.49(14.75)		
174	34.61(15.71)		
182	38.57(17.51)		
197	40.55(18.41)		
212	43.29(19.65)		
227	47.01(21.34)		
242	50.13(22.76)		

Average Oil Consumption Rate: DF-2: 0.207 lb/hr(0.0940 kg/hr)
JP-5: 0.211 lb/hr(0.0958 kg/hr)

TABLE B-11. JP-5 IN THE CUE 1790
ENDURANCE TEST
LUBRICANT ANALYSIS
LUBRICANT: MIL-L-2104C (AL-6856-L)

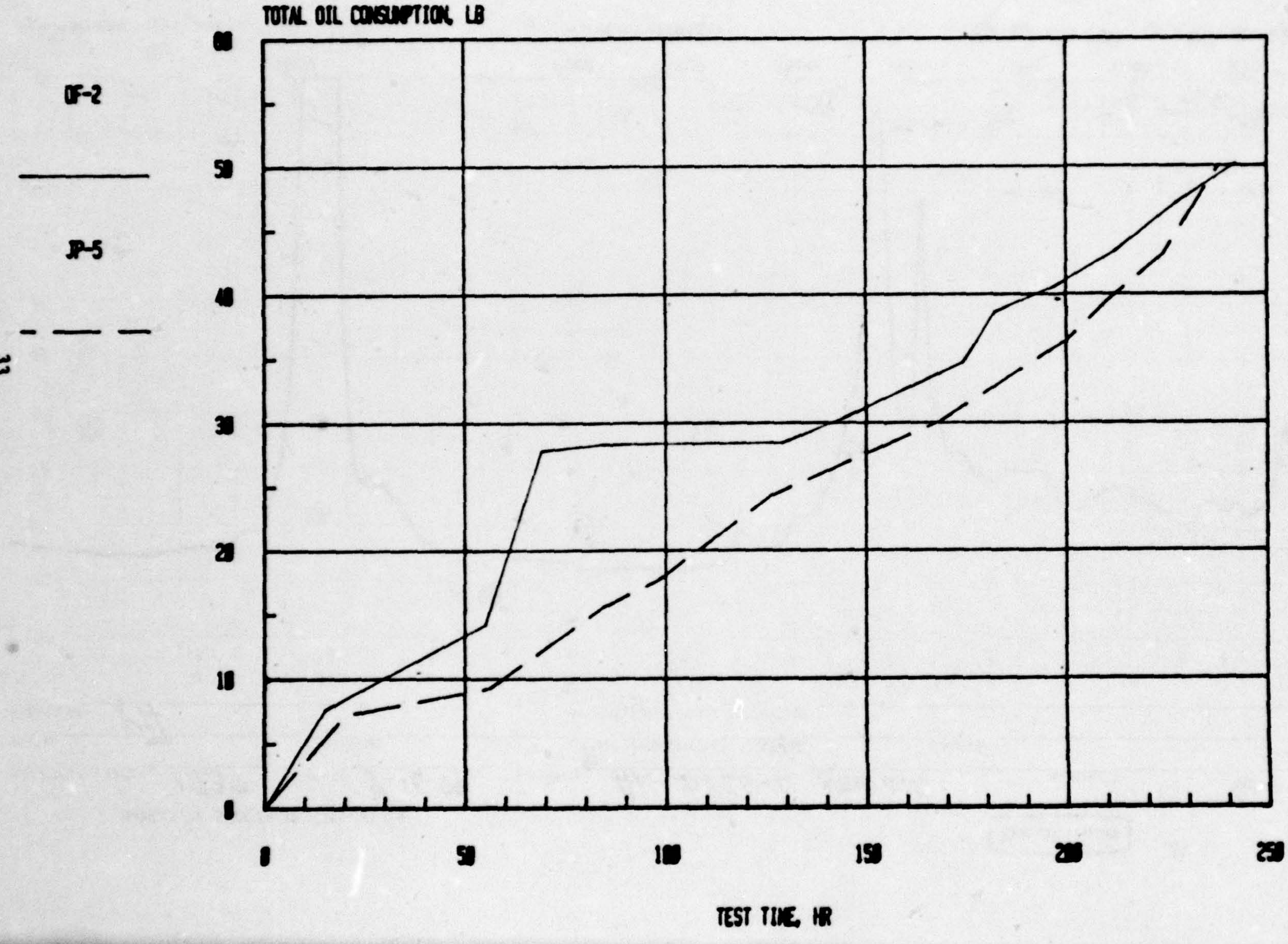
	ASTM Test Method	Test Time, Hours																		
		0	14	28	42	56	70	84	98	112	126	140	154	168	182	196	210	224	238	250
Kinematic Viscosity at 40°C, cSt	D 445	107.5						103.4						100.9						114.7
Kinematic Viscosity at 100°C, cSt	D 445	11.6						11.5						11.8						12.5
Total Acid Number (TAN), mg KOH/g	D 664	2.26						2.42						2.61						2.77
Total Base Number (TBN), mg KOH/g	D 2896	12.75						12.59						12.33						12.47
Pentane Insolubles, w/coagulent, wt%	D 893	0.02						0.23						0.25						0.46
Toluene Insolubles, w/coagulent, wt%	D 893	0.02						0.13						0.23						0.27
Gravity, °API	D 287	25.6						26.0						25.8						25.5
Ramsbottom Carbon Residue, wt%	D 524	1.47						2.01						2.28						2.56
Sulfated Ash, wt%	D 872	1.63						1.64						1.66						1.68
Flash Point, °C	D 92	228						202						208						210
Iron, ppm*	XRF	--	--	--	--	--	--	--	28	22	30	34	36	42	31	32	35	47	38	34
Engine Oil Sample Size, oz.		16	4	4	4	4	4	16	4	4	4	4	16	4	4	4	4	4	4	4

* No other metals detected.
-- Not detected.

FIGURE B-1.

DF-2 AND JP-5 IN THE CUE 1790

ENDURANCE TEST OIL CONSUMPTION



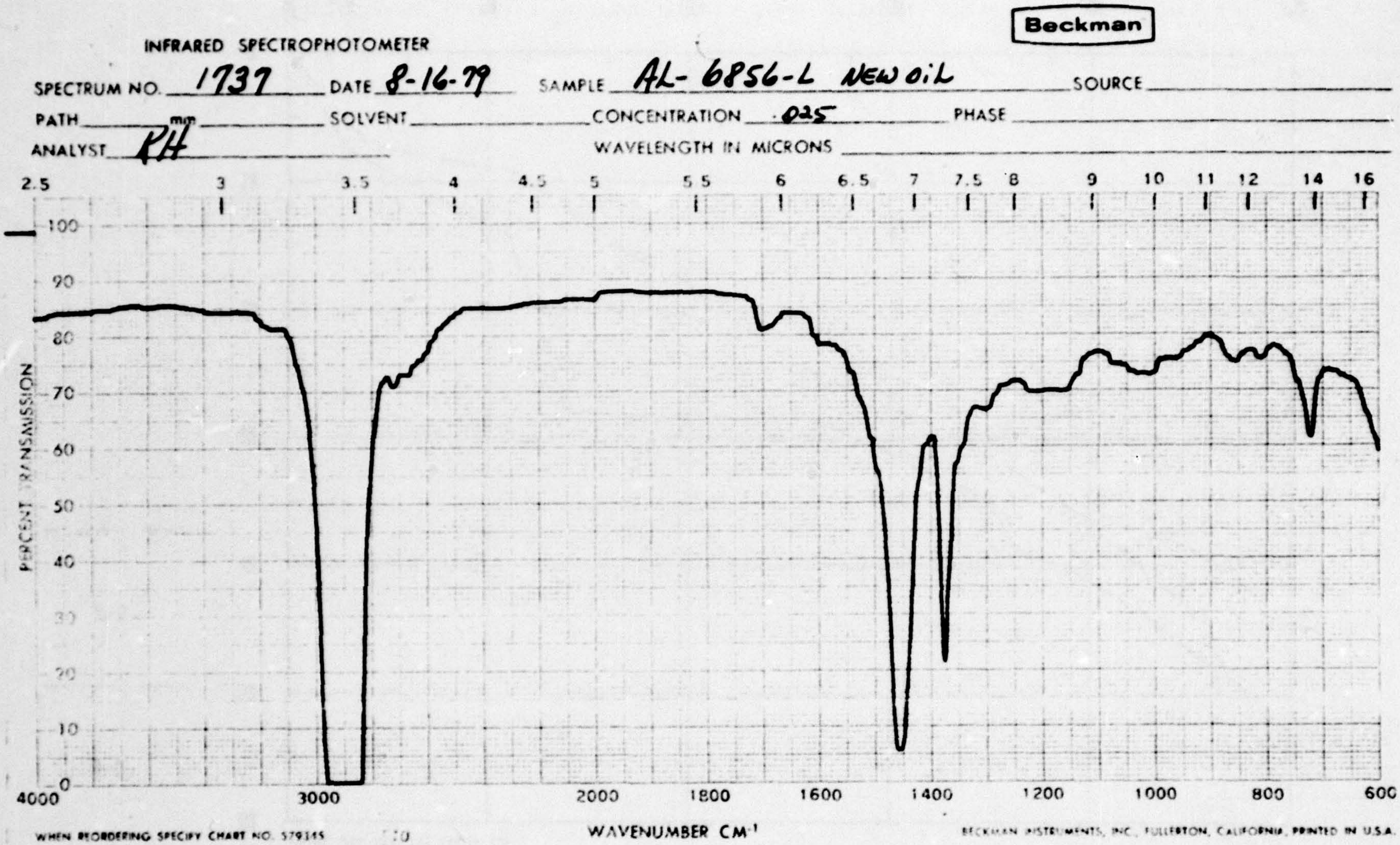


FIGURE B-2. INFRARED SPECTRUM FOR NEW OIL

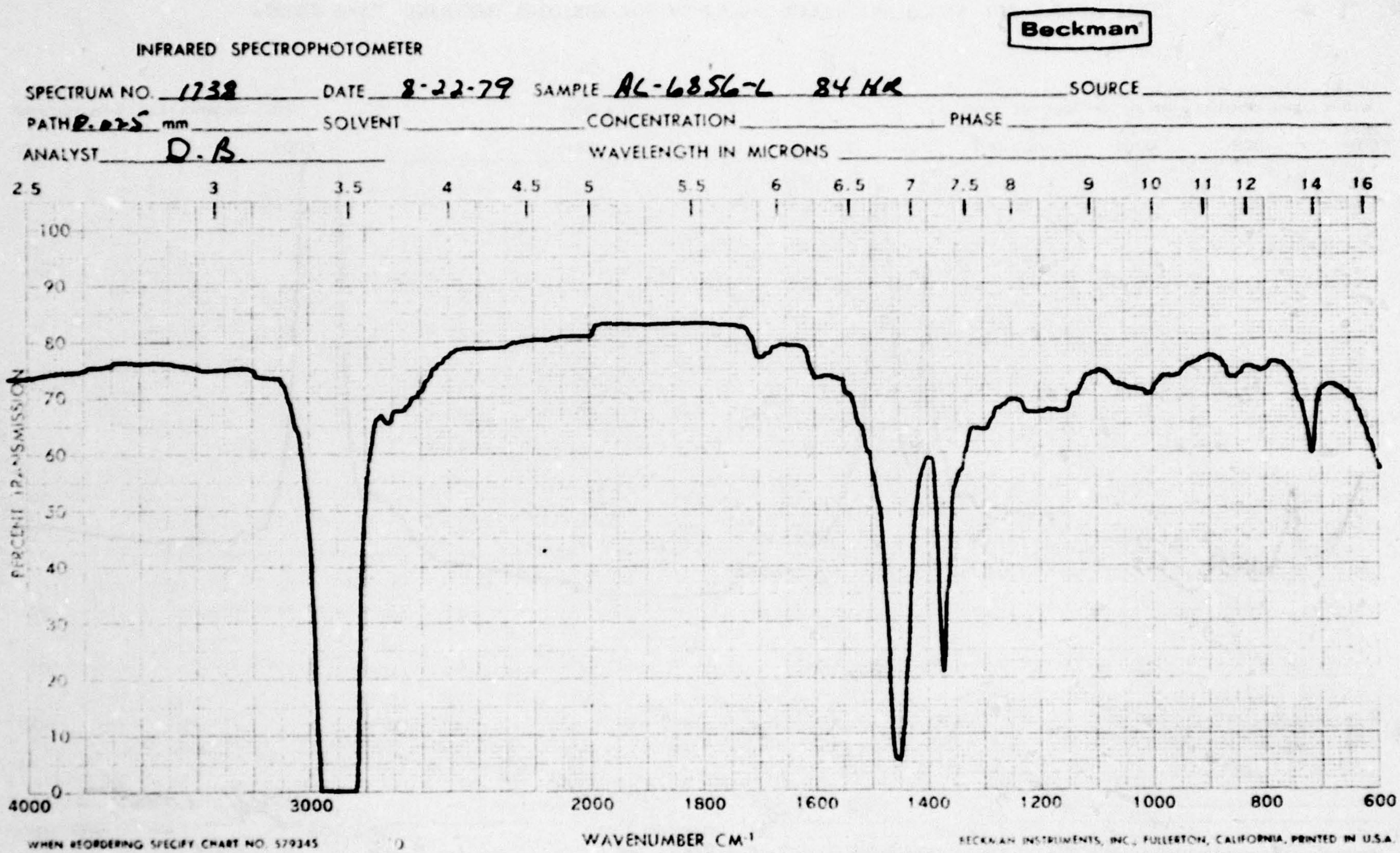


FIGURE B-3. INFRARED SPECTRUM FOR AL-6856-L AFTER 84 HOURS (JP-5 TEST FUEL)

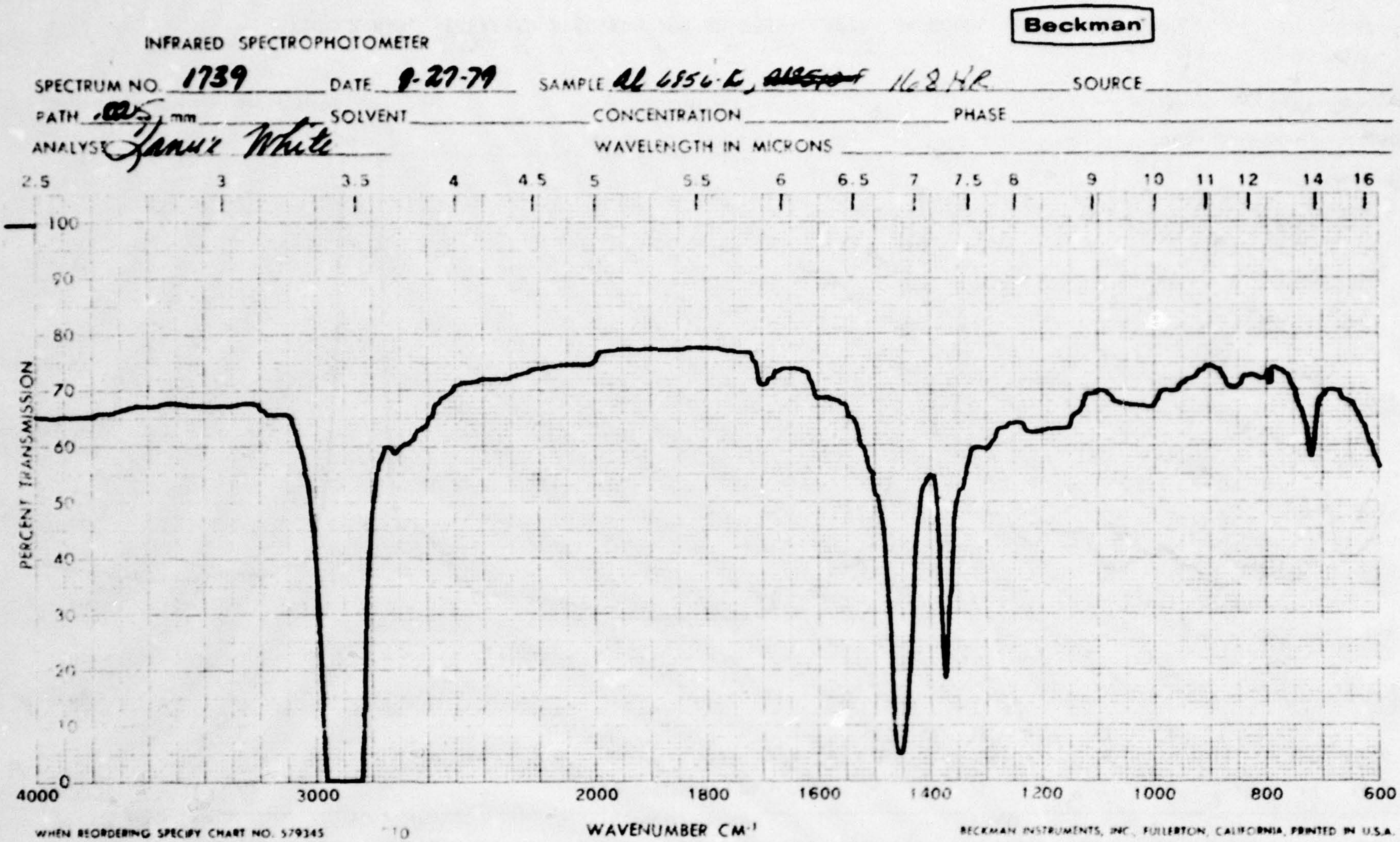


FIGURE B-4. INFRARED SPECTRUM FOR AL-6856-L AFTER 168 HOURS (JP-5 TEST FUEL)

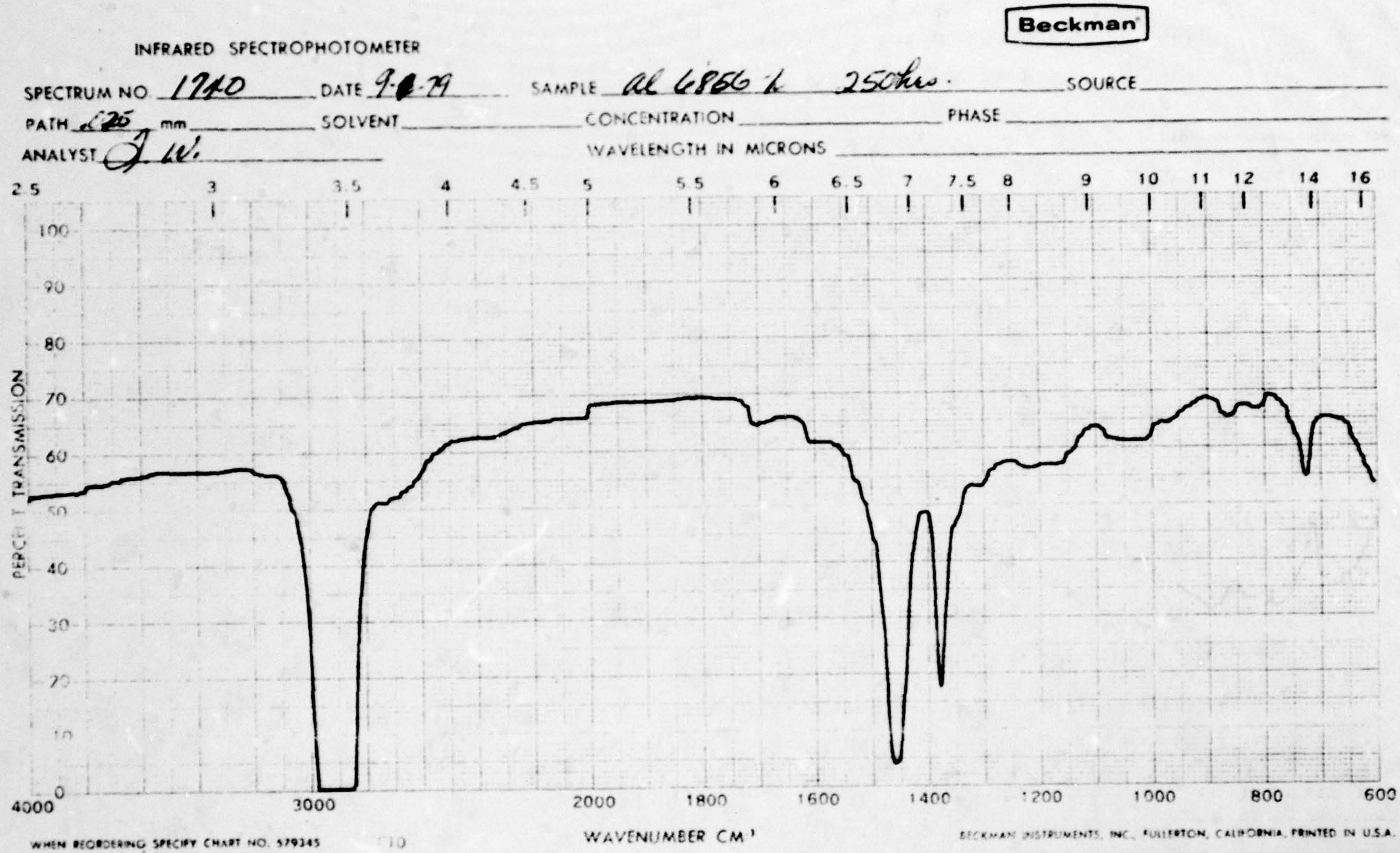


FIGURE B-5. INFRARED SPECTRUM FOR AL-6856-L AFTER 250 HOURS (JP-5 TEST FUEL)

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